

SPECIFICATION

Motor

Technical Field

The present invention relates to a motor comprising a rotor core in
5 which multiple permanent magnets are embedded. More particularly, the
present invention relates to a motor suitable for usage in which silence is
required.

Background Art

From the past, Silence in a motor is considered. There exist many
10 techniques which intend to achieve silence by paying attention to the
variation in attraction force in rotational direction due to rotational position
such as cogging torque, mainly.

For example, Japanese Patent Laid Open Gazette Nos. tokukaihei
10-201147, tokukaihei 11-98731, and tokukai 2000-69695 each intends to
15 reduce cogging torque.

Japanese Patent Laid Open Gazette No. tokukaihei 10-201147
realizes a motor with low vibration and low noise by reducing cogging torque
by determining circumferential direction target position of permanent
magnets in two layers to be a specific relationship which suits to a specific
20 formula, the permanent magnets being embedded in the interior of the rotor
core, as illustrated in Fig. 1.

Japanese Patent Laid Open Gazette No. tokukaihei 10-201147 pays
attention to cogging torque, so that formula differs depending upon the cycle
of cogging torque. Especially, the value of θ in Fig. 1 becomes greater
25 when concentrated winding is employed, so that disadvantage arises in that

permanent magnets disposed in outer peripheral side of the rotor cannot be made greater.

Further, an angle of aperture of a magnetic pole differs for every pole, so that unbalance is generated in rotational force. And, an induction
5 voltage waveform becomes asymmetrical shape. Therefore, various abuse are expected such that increase in noise, affection in position detection accuracy and the like due to other cause.

Japanese Patent Laid Open Gazette No. tokukaihei 11-98731 intends to reduce cogging torque by varying the angle of aperture of the magnetic
10 pole for every pole, as illustrated in Fig. 2.

But, an angle of aperture of a magnetic pole differs for every pole, so that unbalance is generated in rotational force. And, an induction voltage waveform becomes asymmetrical shape. Therefore, various abuse are
15 expected such that increase in noise, affection in position detection accuracy and the like due to other cause.

Japanese Patent Laid Open Gazette No. tokukai 2000-69695 determines the punching holes for embedding permanent magnet which are equal to one another, and varies the shape of elongate hole section each provided to contact to the edge face of the permanent magnet. This
20 corresponds to application of pseudo skew, and intends to reduction effect in cogging torque.

Piling different rotor cores in axial direction causes complicated arrangement of die. Force is generated in axial direction so that thrust vibration is possibly induced. Abuse cannot be ignored due to existence of
25 pole which has extremely narrow angle of aperture in magnetic pole. For

example, problems are exemplified such that increase in iron losses due to excessive concentration of magnetic flux, sufficient magnetic flux cannot reach edge section of permanent magnet during magnetization.

All of those techniques pay attention to cogging torque. When a
5 motor is driven, more particularly when load is great, affection of cogging torque is small, and rather, affection of higher harmonics of induction voltage becomes greater if cogging torque is suppressed below a certain value. More particularly, when permanent magnet having stronger magnetic force is employed such as rare earth magnet, it is understood that the magnet is
10 greatly affected by higher harmonics of induction voltage.

Japanese Patent Laid Open Gazette No. tokukai 2002-44888 can resolve the problem of the existence of extremely narrow angle of aperture in magnetic pole among the above problems. Specifically, an elongate hole section provided for contacting the edge face of the permanent magnet is
15 divided in peripheral direction, as illustrated in Fig. 4, so that "auxiliary reinforcement rib" is provided. Japanese Patent Laid Open Gazette No. tokukai 2002-44888 intends to prevent deformation in the rotor.

The magnetic flux also flows through the "auxiliary reinforcement rib". Therefore, sound may be increased depending upon the position of the
20 "auxiliary reinforcement rib".

As is described in the above, Japanese Patent Laid Open Gazette Nos. tokukaihei 10-201147, tokukaihei 11-98731, tokukai 2000-69695, and tokukai 2002-44888 do not successfully reduce cogging torque while sufficient permanent magnet magnetic flux is maintained and abuse in
25 sound due to unbalance vibration and in sound due to thrust force is not

generated. Also, they are not the measure which pays attention to specific harmonics of the induction voltage, for example fifth order harmonics and seventh order harmonics. Especially, they are not the arrangement for sufficiently reduce sound when the motor has a great load.

5 The present invention was made in view of the above problems.

It is an object of the present invention to provide a motor for reducing specific orders of magnetic flux distribution waveform, for example fifth order and seventh order, and for prevent generation of unnecessary radial force and thrust force while sufficient magnetic flux is maintained.

10 Summary of the Invention

A motor of first aspect comprises a rotor core, plural permanent magnets embedded in the rotor core, wherein a peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet
15 elongates in the vicinity between the poles to the vicinity of the rotor surface, and a second non-magnetic layer is provided in the vicinity of the surface of the rotor at the pole center side position with respect to the peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the peripheral direction edge section of each
20 permanent magnet, and wherein the non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the second non-magnetic layer are positioned to cancel n-th order harmonics (n is an odd number and is equal to or greater than 3) of the induction voltage.

25 A motor of second aspect employs an odd number order harmonics,

the odd number being equal to or greater than 3 and other than multiples of 3, as the n-th order harmonics.

A motor of third aspect employs an odd number order harmonics, the odd number being equal to or greater than 13 and other than multiples of 3,
5 as the n-th order harmonics.

A motor of fourth aspect employs 5-th order harmonics or 7-th order harmonics as the n-th order harmonics.

A motor of fifth aspect makes the peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the
10 peripheral direction edge section of each permanent magnet and the second non-magnetic layer independent from one another, and provides rotor core lying between them.

A motor of sixth aspect determines $\theta 1$ and $\theta 2$ to be

$$0 < \theta 1 < 180/(5 \cdot P_n)$$

15 and

$$180/(5 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(5 \cdot P_n)$$

or

$$0 < \theta 1 < 180/(7 \cdot P_n)$$

and

$$20 \quad 180/(7 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(7 \cdot P_n)$$

where $\theta 1$ represents an angle between the peripheral direction edge section of each permanent magnet or the pole center side edge section of rotor surface adjacent section of the non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the
25 between poles, and $\theta 2$ represents an angle between pole center side edge

section of the rotor surface adjacent section of the second non-magnetic layer and the between poles, and P_n represents a pole pair number.

A motor of seventh aspect determines the angle θ_1 to be $0 < \theta_1 < 180/(5 \cdot P_n)$ or $0 < \theta_1 < 180/(7 \cdot P_n)$, the angle θ_2 to be the minimum value of
 5 $180/(5 \cdot P_n) \leq \theta_2 \leq 180 \times 2/(5 \cdot P_n)$ or the minimum value of $180/(7 \cdot P_n) \leq \theta_2 \leq 180 \times 2/(7 \cdot P_n)$.

A motor of eighth aspect determines θ_5 and θ_6 to be
 $0 < \theta_5 < 180/(5 \cdot P_n)$

and

10 $180/(5 \cdot P_n) \leq \theta_6 \leq 180 \times 2/(5 \cdot P_n)$

where θ_5 represents an angle between the peripheral direction edge section of each permanent magnet or the pole center side edge section of the rotor surface adjacent section of the non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the
 15 between poles, and θ_6 represents an angle between pole center side edge section of the rotor surface adjacent section of the second non-magnetic layer and the between poles, and P_n represents a pole pair number,
 and determines θ_7 and θ_8 to be

$0 < \theta_7 < 180/(7 \cdot P_n)$

20 and

$180/(7 \cdot P_n) \leq \theta_8 \leq 180 \times 2/(7 \cdot P_n)$

where the rotor core section width has points of inflection, the rotor core section width being sandwiched by the peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the
 25 peripheral direction edge section of each permanent magnet and the second

non-magnetic layer and the rotor surface, $\theta 7$ and $\theta 8$ represent angles between the respective point of inflection and the between poles, and P_n represents a pole pair number,

and determines the relationship of the angles $\theta 5$, $\theta 6$, $\theta 7$ and $\theta 8$ to be θ

5 $7 < \theta 5 < \theta 8 < \theta 6$.

A motor of ninth aspect determines the angle $\theta 5$ to be $0 < \theta 5 < 180/(5 \cdot P_n)$, the angle $\theta 7$ to be $0 < \theta 7 < 180/(7 \cdot P_n)$, the angle $\theta 6$ to be the minimum value of $180/(5 \cdot P_n) \leq \theta 6 \leq 180 \times 2/(5 \cdot P_n)$, and the angle $\theta 8$ to be the minimum value of $180/(7 \cdot P_n) \leq \theta 8 \leq 180 \times 2/(7 \cdot P_n)$.

10 A motor of tenth aspect employs a permanent magnet divided into multiple layers in radial direction as each of the permanent magnets.

A motor of eleventh aspect employs a permanent magnet divided into two layers in radial direction as each of the permanent magnets, and determines $\theta 3$ and $\theta 4$ to be

15 $0 < \theta 3 < 180/(5 \cdot P_n)$

and

$180/(5 \cdot P_n) \leq \theta 4 \leq 180 \times 2/(5 \cdot P_n)$

or

$0 < \theta 3 < 180/(7 \cdot P_n)$

20 and

$180/(7 \cdot P_n) \leq \theta 4 \leq 180 \times 2/(7 \cdot P_n)$

where $\theta 3$ represents an angle between the peripheral direction edge section of permanent magnet in inner side of the rotor or the pole center side edge section of rotor surface adjacent section of the non-magnetic layer continuous

25 or adjacent to the peripheral direction edge section of each permanent

magnet and the between poles, and $\theta 4$ represents an angle between the peripheral direction edge section of permanent magnet in outer side of the rotor or pole center side edge section of the rotor surface adjacent section of the non-magnetic layer continuous or adjacent to peripheral direction edge section of the permanent magnet and the between poles, and P_n represents a pole pair number.

A motor of twelfth aspect determines the angle $\theta 3$ to be $0 < \theta 3 < 180/(5 \cdot P_n)$ or $0 < \theta 3 < 180/(7 \cdot P_n)$, the angle $\theta 4$ to be the minimum value of $180/(5 \cdot P_n) \leq \theta 4 \leq 180 \times 2/(5 \cdot P_n)$ or the minimum value of $180/(7 \cdot P_n) \leq \theta 4 \leq 180 \times 2/(7 \cdot P_n)$.

A motor of thirteenth aspect employs a permanent magnet divided into two layers in radial direction as each of the permanent magnets, and determines $\theta 9$ and $\theta 10$ to be

$$0 < \theta 9 < 180/(5 \cdot P_n)$$

and

$$180/(5 \cdot P_n) \leq \theta 10 \leq 180 \times 2/(5 \cdot P_n)$$

where $\theta 9$ represents an angle between the pole center side edge section of rotor surface adjacent section of the permanent magnet in inner side of the rotor and the between poles, and $\theta 10$ represents an angle between pole center side edge section of the rotor surface adjacent section of the permanent magnet in outer side of the rotor and the between poles, and P_n represents a pole pair number,

and determines $\theta 11$ and $\theta 12$ to be

$$0 < \theta 11 < 180/(7 \cdot P_n)$$

and

$$180/(7 \cdot P_n) \leq \theta_{12} \leq 180 \times 2/(7 \cdot P_n)$$

where the rotor core section width has points of inflection, the rotor core section width being sandwiched by the peripheral direction edge section of permanent magnet on inner side of the rotor or non-magnetic layer continuous or adjacent to the peripheral direction edge section of permanent magnet and the peripheral direction edge section of permanent magnet on outer side of the rotor or non-magnetic layer continuous or adjacent to the peripheral direction edge section of permanent magnet, θ_{11} and θ_{12} represent angles between the respective point of inflection and the between poles, and P_n represents a pole pair number,

and determines the relationship of the angles θ_9 , θ_{10} , θ_{11} and θ_{12} to be $\theta_{11} < \theta_9 < \theta_{12} < \theta_{10}$.

A motor of fourteenth aspect determines the angle θ_9 to be $0 < \theta_9 < 180/(5 \cdot P_n)$, the angle θ_{11} to be $0 < \theta_{11} < 180/(7 \cdot P_n)$, the angle θ_{10} to be the minimum value of $180/(5 \cdot P_n) \leq \theta_{10} \leq 180 \times 2/(5 \cdot P_n)$, and the angle θ_{12} to be the minimum value of $180/(7 \cdot P_n) \leq \theta_{12} \leq 180 \times 2/(7 \cdot P_n)$.

In this specification "pole" is used to represent N-poles or S-poles which are disposed at every approximately constant interval or constant angle. "magnetic pole" is used to represent an extent from which magnetic flux of the permanent magnet mainly flows.

The invention of first aspect comprises a rotor core, plural permanent magnets embedded in the rotor core, wherein a peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet elongates in the vicinity of between the poles to the vicinity of the rotor

surface, and a second non-magnetic layer is provided in the vicinity of the surface of the rotor at the pole center side position with respect to the peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet, and wherein the non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the second non-magnetic layer are positioned to cancel n -th order harmonics (n is an odd number and is equal to or greater than 3) of the induction voltage. Therefore, n -th order harmonics component of the magnetic flux distribution waveform (induction voltage waveform) can be reduced and unnecessary radial force and thrust force can be prevented from occurrence, while sufficient magnetic flux can be maintained.

A motor of second aspect employs harmonics of an order of odd number and of equal to or greater than 3 other than multiples of 3, as the n -th order harmonics. Therefore, odd number order harmonics, the odd number being equal to or greater than 3 other than multiples of 3, of the magnetic flux distribution waveform (induction voltage waveform) can be reduced and unnecessary radial force and thrust force can be prevented from occurrence, while sufficient magnetic flux can be maintained.

A motor of third aspect employs harmonics of an order of odd number and of equal to or greater than 13 other than multiples of 3, as the n -th order harmonics. Therefore, odd number order harmonics, the odd number being equal to or greater than 13 other than multiples of 3, of the magnetic flux distribution waveform (induction voltage waveform) can be reduced and unnecessary radial force and thrust force can be prevented from occurrence,

while sufficient magnetic flux can be maintained.

A motor of fourth aspect employs fifth order harmonics or seventh order harmonics as the n-th order harmonics. Therefore, 5-th order harmonics or 7-th order harmonics of the magnetic flux distribution waveform (induction voltage waveform) can be reduced and unnecessary radial force and thrust force can be prevented from occurrence, while sufficient magnetic flux can be maintained.

A motor of fifth aspect makes the peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the second non-magnetic layer independent from one another, and provides rotor core lying between them. Therefore, mechanical strength can be improved, and operation and effect similar to those of the fourth aspect can be realized.

A motor of sixth aspect determines $\theta 1$ and $\theta 2$ to be

$$0 < \theta 1 < 180/(5 \cdot P_n)$$

and

$$180/(5 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(5 \cdot P_n)$$

or

$$0 < \theta 1 < 180/(7 \cdot P_n)$$

and

$$180/(7 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(7 \cdot P_n)$$

where $\theta 1$ represents an angle between the peripheral direction edge section of each permanent magnet or the pole center side edge section of rotor surface adjacent section of the non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the

between poles, and $\theta 2$ represents an angle between pole center side edge section of the rotor surface adjacent section of the second non-magnetic layer and the between poles, and P_n represents a pole pair number. Therefore, operation and effect similar to those of fourth aspect or fifth aspect can be realized by taking symmetry into consideration.

A motor of seventh aspect determines the angle $\theta 1$ to be $0 < \theta 1 < 180/(5 \cdot P_n)$ or $0 < \theta 1 < 180/(7 \cdot P_n)$, the angle $\theta 2$ to be the minimum value of $180/(5 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(5 \cdot P_n)$ or the minimum value of $180/(7 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(7 \cdot P_n)$. Therefore, silencing can be realized, and operation and effect similar to those of fourth aspect or fifth aspect can be realized.

A motor of eighth aspect determines $\theta 5$ and $\theta 6$ to be

$$0 < \theta 5 < 180/(5 \cdot P_n)$$

and

$$180/(5 \cdot P_n) \leq \theta 6 \leq 180 \times 2/(5 \cdot P_n)$$

where $\theta 5$ represents an angle between the peripheral direction edge section of each permanent magnet or the pole center side edge section of the rotor surface adjacent section of the non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the between poles, and $\theta 6$ represents an angle between pole center side edge section of the rotor surface adjacent section of the second non-magnetic layer and the between poles, and P_n represents a pole pair number,

and determines $\theta 7$ and $\theta 8$ to be

$$0 < \theta 7 < 180/(7 \cdot P_n)$$

and

$$180/(7 \cdot P_n) \leq \theta 8 \leq 180 \times 2/(7 \cdot P_n)$$

where the rotor core section width has points of inflection, the rotor core section width being sandwiched by the peripheral direction edge section of each permanent magnet or non-magnetic layer continuous or adjacent to the peripheral direction edge section of each permanent magnet and the second
 5 non-magnetic layer and the rotor surface, $\theta 7$ and $\theta 8$ represent angles between the respective point of inflection and the between poles, and P_n represents a pole pair number,

and determines the relationship of the angles $\theta 5$, $\theta 6$, $\theta 7$ and $\theta 8$ to be $\theta 7 < \theta 5 < \theta 8 < \theta 6$. Therefore, operation and effect similar to those of
 10 fourth aspect or fifth aspect can be realized by taking symmetry into consideration.

A motor of ninth aspect determines the angle $\theta 5$ to be $0 < \theta 5 < 180/(5 \cdot P_n)$, the angle $\theta 7$ to be $0 < \theta 7 < 180/(7 \cdot P_n)$, the angle $\theta 6$ to be the minimum value of $180/(5 \cdot P_n) \leq \theta 6 \leq 180 \times 2/(5 \cdot P_n)$, and the angle $\theta 8$
 15 to be the minimum value of $180/(7 \cdot P_n) \leq \theta 8 \leq 180 \times 2/(7 \cdot P_n)$. Therefore, silencing can be realized, and operation and effect similar to those of fourth aspect or fifth aspect can be realized.

A motor of tenth aspect employs a permanent magnet divided into multiple layers in radial direction as each of the permanent magnets.
 20 Therefore, operation and effect similar to those of first to fourth aspect can be realized even when the permanent magnet is divided into multiple parts, some parts corresponding to inner side of the rotor and other parts corresponding to outer side of the rotor.

A motor of eleventh aspect employs a permanent magnet divided into
 25 two layers in radial direction as each of the permanent magnets, and

determines θ_3 and θ_4 to be

$$0 < \theta_3 < 180/(5 \cdot P_n)$$

and

$$180/(5 \cdot P_n) \leq \theta_4 \leq 180 \times 2/(5 \cdot P_n)$$

5 or

$$0 < \theta_3 < 180/(7 \cdot P_n)$$

and

$$180/(7 \cdot P_n) \leq \theta_4 \leq 180 \times 2/(7 \cdot P_n)$$

where θ_3 represents an angle between the peripheral direction edge section
 10 of permanent magnet in inner side of the rotor or the pole center side edge
 section of rotor surface adjacent section of the non-magnetic layer continuous
 or adjacent to the peripheral direction edge section of each permanent
 magnet and the between poles, and θ_4 represents an angle between pole
 center side edge section of the rotor surface adjacent section of the peripheral
 15 direction edge section of permanent magnet in outer side of the rotor or
 non-magnetic layer continuous or adjacent to peripheral direction edge
 section of the permanent magnet and the between poles, and P_n represents a
 pole pair number. Therefore, operation and effect similar to those of tenth
 aspect can be realized by taking symmetry into consideration.

20 A motor of twelfth aspect determines the angle θ_3 to be $0 < \theta_3 < 180/(5 \cdot P_n)$ or $0 < \theta_3 < 180/(7 \cdot P_n)$, the angle θ_4 to be the minimum value
 of $180/(5 \cdot P_n) \leq \theta_4 \leq 180 \times 2/(5 \cdot P_n)$ or the minimum value of $180/(7 \cdot P_n) \leq \theta_4 \leq 180 \times 2/(7 \cdot P_n)$. Therefore, silencing can be realized, and
 operation and effect similar to those of tenth aspect can be realized.

25 A motor of thirteenth aspect employs a permanent magnet divided into two

layers in radial direction as each of the permanent magnets, and determines $\theta 9$ and $\theta 10$ to be

$$0 < \theta 9 < 180/(5 \cdot P_n)$$

and

$$5 \quad 180/(5 \cdot P_n) \leq \theta 10 \leq 180 \times 2/(5 \cdot P_n)$$

where $\theta 9$ represents an angle between the pole center side edge section of rotor surface adjacent section of the permanent magnet in inner side of the rotor and the between poles, and $\theta 10$ represents an angle between pole center side edge section of the rotor surface adjacent section of the permanent magnet in outer side of the rotor and the between poles, and P_n represents a pole pair number,

and determines $\theta 11$ and $\theta 12$ to be

$$0 < \theta 11 < 180/(7 \cdot P_n)$$

and

$$15 \quad 180/(7 \cdot P_n) \leq \theta 12 \leq 180 \times 2/(7 \cdot P_n)$$

where the rotor core section width has points of inflection, the rotor core section width being sandwiched by the peripheral direction edge section of permanent magnet on inner side of the rotor or non-magnetic layer continuous or adjacent to the peripheral direction edge section of permanent magnet and the peripheral direction edge section of permanent magnet on outer side of the rotor or non-magnetic layer continuous or adjacent to the peripheral direction edge section of permanent magnet, $\theta 11$ and $\theta 12$ represent angles between the respective point of inflection and the between poles, and P_n represents a pole pair number,

25 and determines the relationship of the angles $\theta 9$, $\theta 10$, $\theta 11$ and $\theta 12$ to be

$\theta_{11} < \theta_9 < \theta_{12} < \theta_{10}$. Therefore, operation and effect similar to those of tenth aspect can be realized by taking symmetry into consideration.

A motor of fourteenth aspect determines the angle θ_9 to be $0 < \theta_9 < 180/(5 \cdot P_n)$, the angle θ_{11} to be $0 < \theta_{11} < 180/(7 \cdot P_n)$, the angle θ_{10} to be the minimum value of $180/(5 \cdot P_n) \leq \theta_{10} \leq 180 \times 2/(5 \cdot P_n)$, and the angle θ_{12} to be the minimum value of $180/(7 \cdot P_n) \leq \theta_{12} \leq 180 \times 2/(7 \cdot P_n)$. Therefore, silencing can be realized, and operation and effect similar to those of tenth aspect can be realized.

Brief Description Of The Drawings

Figure 1 is a schematic diagram illustrating an example of a prior motor;

Figure 2 is a schematic diagram illustrating another example of a prior motor;

Figure 3 is a schematic diagram illustrating a further example of a prior motor;

Figure 4 is a schematic diagram illustrating a further example of a prior motor;

Figure 5 is a diagram illustrating magnetic flux density distribution in peripheral direction on rotor surface;

Figure 6 is a cross-sectional view illustrating a rotor of a motor of first embodiment according to the present invention;

Figure 7 is a diagram illustrating a relationship between the magnetic flux density distribution on the rotor surface and the non-magnetic layer;

Figure 8 is a diagram illustrating characteristics of 5-th order

harmonics, 7-th order harmonics with respect to θ_1 when $\theta_2 = 23^\circ$;

Figure 9 is a diagram illustrating characteristics of 5-th order harmonics, 7-th order harmonics with respect to θ_2 when $\theta_1 = 6^\circ$;

Figure 10 is a schematic diagram illustrating a stator having distributed winding;

Figure 11 is a schematic diagram illustrating a stator having concentrated winding;

Figure 12 is a schematic diagram illustrating a modified example of the rotor of first embodiment;

Figure 13 is a schematic diagram illustrating another modified example of the rotor of first embodiment;

Figure 14 is a schematic diagram illustrating a rotor of the motor of second embodiment according to the present invention;

Figure 15 is a schematic diagram illustrating a modified example of the rotor of second embodiment;

Figure 16 is a schematic diagram illustrating a rotor of the motor of third embodiment according to the present invention;

Figure 17 is a diagram illustrating magnetic flux density distribution on rotor surface;

Figure 18 is a diagram illustrating comparison of the induction voltage waveform for a case where second non-magnetic layer does not exist, and the induction voltage waveform for a case where third embodiment is employed;

Figure 19 is a diagram illustrating higher harmonics component of noise for a case the motor is driven as the motor for compressor;

Figure 20 is a schematic diagram illustrating a modified example of the rotor of third embodiment; and

Figure 21 is a schematic diagram illustrating a rotor of the motor of fourth embodiment according to the present invention.

5 Best Mode For Carrying Out The Invention

Hereinafter, referring to the attached drawings, we explain a motor of an embodiment according to the present invention in detail.

In the following embodiment, we explain a case which cancels 5-th order harmonics and/or 7-th order harmonics of an induction voltage. But, it is of
10 course possible that other harmonics can be canceled.

First, a general example of a motor is described.

Magnetic flux density distribution in peripheral direction of the rotor surface of the motor is symmetric for every pole. When each pole has approximately same shape to one another, magnetic flux density becomes
15 zero for between poles.

Therefore, the magnetic flux density distribution in peripheral direction of the rotor surface becomes a distribution which makes 1 pole pair to be fundamental wave, and includes odd number order thereof. For example, when a simple rectangular wave is applied Fourier expansion, odd
20 number order components such as third order, 5-th order, 7-th order, and 9-th order, are overlapped to the fundamental wave, as is illustrated in Fig. 5. Wherein, $3n$ -th order harmonics vibration addition forces (where n : 1, 2, 3, 4, ...) such as third order and 9-th order harmonics vibration addition forces are in synchronism to one another so that a mode of resonance having a
25 number which is the same to the stator pole number, such that hexagon

mode of resonance for the stator having 6 poles. The mode of resonance of higher order generally exceed the audible range greatly so that the mode of resonance hardly becomes noise.

Further, 5-th order and 7-th order have characteristics which is
5 greater in amplitude, easier in becoming sound, and more difficult to be cut-off because of low frequency, in comparison to eleventh or more orders. Therefore, we will pay attention to 5-th order harmonics and 7-th order harmonics.

The following two points may be made to be premises when the 5-th
10 order harmonics and 7-th order harmonics are taken measure to meet with.

- 1) Every order component becomes zero due to the symmetry of magnetic flux density waveform on the rotor surface.
- 2) Higher harmonics component can be zero-cross at the location where varying in magnetic flux begins suddenly such as beginning of magnetic pole
15 and the like.

(First Embodiment)

Hereinafter, the first embodiment is described with reference to the drawings.

Fig. 6 is a schematic diagram illustrating an arrangement of a rotor
20 of a motor of the first embodiment according to the present invention.

This rotor 1 comprises multiple permanent magnets 3 (in this embodiment, the rotor has 4 poles, therefore 4 permanent magnets 3) which are embedded in the interior of the rotor core 2.

Further, non-magnetic layers 4 (hereinafter, referred to as "first
25 non-magnetic layer"), each being continuous to the peripheral direction edge

section of each permanent magnet 3, each elongates in vicinity of the between poles to the vicinity of the rotor surface. And, a second non-magnetic layer 5 is provided at a location which is a pole center side location of the first non-magnetic layer 4 and which is in vicinity of the rotor surface. Wherein, the non-magnetic layer is a through hole or an air layer.

The first non-magnetic layer 4 and second non-magnetic layer 5 are independent from one another. An auxiliary reinforcement rib 2a made of rotor core is interposed between both non-magnetic layers.

An angle $\theta 1$ between the pole center side edge section of rotor surface adjacent section and the between poles of the first non-magnetic layer 4, and an angle $\theta 2$ between the pole center side edge section of rotor surface adjacent section and the between poles of the second non-magnetic layer 5 are determined to be

$$0 < \theta 1 < 180/(5 \cdot P_n)$$

and

$$180/(5 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(5 \cdot P_n)$$

or

$$0 < \theta 1 < 180/(7 \cdot P_n)$$

and

$$180/(7 \cdot P_n) \leq \theta 2 \leq 180 \times 2/(7 \cdot P_n)$$

when the pole pair number is P_n . The above formulae correspond to reduction in 5-th order harmonics and reduction in 7-th order harmonics. When the reduction of n-th order harmonics (n is odd number and is equal to or greater than 3) is to be carried out, n is employed instead 5 and 7.

Similar operation should be carried out for following formulae.

In this embodiment, the pole pair number $P_n = 2$. Formulae of upper two rows are used for reducing the 5-th order harmonics. Specifically, it is better that $\theta_1 = 9^\circ$, $\theta_2 = 18^\circ$.

The principle for reducing sound of the motor having the above arrangement is described in the following.

For example, since 5-th order harmonics is intended to be reduced and the pole pair number is 2, when $\theta_1 = 0^\circ$, and $\theta_2 = 18^\circ$, the phases are shifted by 180° so as to cancel from one another. But, $\theta_1 = 0^\circ$ is difficult for the arrangement where the permanent magnets are embedded in the interior of the rotor core. Consequently, it is sufficient that $\theta_1 < 18^\circ$ due to symmetry. When 7-th order harmonics is to be reduced, formulae of lower two rows are used, and it is better that $\theta_1 < 12.9^\circ$, $12.9^\circ \leq \theta_2 \leq 25.7^\circ$. For maximizing the torque, θ_2 is increased as great as possible so as to increase the magnetic flux interlinking to the permanent magnet.

Fig. 7 illustrates a relationship between the magnetic flux density distribution on the rotor surface and the non-magnetic layers 4 and 5, of this embodiment. In some portion of the non-magnetic layers 4 and 5, the magnetic flux density increases or decreases, and in remaining portion of the non-magnetic layers 4 and 5, the magnetic flux density is approximately constant. Therefore, changing in magnetic flux becomes steep from pole center side edge section of the rotor surface adjacent portion of respective non-magnetic layers 4 and 5. Consequently, zero-cross points of higher harmonics components appear for respective points. For the second non-magnetic layer 5, it corresponds to 1 wave length of the 5/7-th order harmonics from the between poles, and it is thought that the zero-cross point

becomes the between poles due to symmetry. For the first non-magnetic layer 4, it corresponds to half wave length of the 5/7-th order harmonics from the between poles, and it is thought that the zero-cross point becomes the between poles due to symmetry. Therefore, 5/7-th order harmonics due to
 5 respective non-magnetic layers 4 and 5 are shifted by half wave length from one another, so that they are canceled one another.

Fig. 8 illustrates characteristics of 5-th order harmonics and 7-th order harmonics with respect to θ_1 when $\theta_2 = 23^\circ$, while Fig. 9 illustrates characteristics of 5-th order harmonics and 7-th order harmonics with
 10 respect to θ_2 when $\theta_1 = 6^\circ$.

It is understood from Figs. 8 and 9, greater reduction effect of 5-th order harmonics and 7-th order harmonics can be realized by determining the angle θ_1 , and θ_2 to satisfy the above formulae.

Wherein, the width of the rotor core sandwiched by the first non-magnetic layer 4, second non-magnetic layer 5 and the rotor surface (hereinafter, referred to as “first bridge 2b1” and “second bridge 2b2”) are constant. It is desirable that the width is made smaller for preventing magnetic flux leakage.
 15

Further, there also exist a rotor rib (auxiliary reinforcement rib) 2a serving as the magnetic path between the first non-magnetic layer 4 and second non-magnetic layer 5. Sufficient effect cannot be obtained by passing the magnetic flux of the permanent magnet through the auxiliary reinforcement rib 2a.
 20

The permanent magnet and non-magnetic layer need not be in continuous to one another. They may adjacent to one another by a short
 25

distance.

The stator of the motor according to the present invention may have distributed winding as illustrated in Fig. 10, or may have concentrated winding as illustrated in Fig. 11. Especially, 5-th order harmonics and 7-th order harmonics become extremely greater for concentrated winding, therefore application of the present invention is effective.

Figs. 12 and 13 illustrate schematic diagram illustrating modified examples of Fig. 6.

Fig. 12 is a modified example in which rotor core 2c exist in vicinity of both side of the permanent magnet of the rotor of Fig. 6. When the first and second non-magnetic layers 6 and 7 are disposed for canceling the higher harmonics wave of the magnetic flux flowing out from the surface, sufficient effect can be obtained.

Fig. 13 is a modified example in which the permanent magnet layer exist to a region adjacent to the rotor surface. When the second non-magnetic layer 8 is disposed for canceling the higher harmonics wave of the magnetic flux flowing out from the surface, sufficient effect can similarly be obtained. In this case, it is necessary to magnetize the permanent magnet so that the magnet flux at the permanent magnet edge section does not flow out in normal direction of the rotor.

(Second Embodiment)

Fig. 14 is a schematic diagram illustrating a rotor of a motor of a second embodiment according to the present invention.

In the rotor 11, permanent magnets are embedded in the interior of the rotor core 12. Permanent magnets for each pole is divided into 2 layers

in radial direction (13: permanent magnet at inner side of the rotor, and 14: permanent magnet at outer side of the rotor). Further, peripheral direction edge sections 13a, and 14a of each of the permanent magnets 13, and 14 elongate in the vicinity to the between poles to the vicinity of the rotor surface.

The peripheral direction edge sections 13a and 14a of the permanent magnet 13 at inner side of the rotor and of the permanent magnet 14 at outer side of the rotor are independent from one another. A so-called q-axis magnetic flux path 12a made of rotor core is interposed between them.

Due to the existence of the q-axis magnetic flux path 12a, q-axis inductance L_q can be made to be greater so that the reluctance torque can be utilized in greater part, and that the magnetic flux of the permanent magnet can be increased without increasing the rotor in size.

An angle θ_3 between the pole center side edge section of the peripheral direction edge section 13a of the permanent magnet 13 in inner side of the rotor and the between poles, and an angle θ_4 between the pole center side edge section of the peripheral direction edge section 14a of the permanent magnet 14 in inner side of the rotor and the between poles are determined to be

$$0 < \theta_3 < 180/(5 \cdot P_n)$$

and

$$180/(5 \cdot P_n) \leq \theta_4 \leq 180 \times 2/(5 \cdot P_n)$$

or

$$0 < \theta_3 < 180/(7 \cdot P_n)$$

and

$$180/(7 \cdot P_n) \leq \theta_4 \leq 180 \times 2/(7 \cdot P_n)$$

when the pole pair number is P_n .

In this embodiment, the pole pair number $P_n = 2$. Formulae of upper two rows are used for reducing the 5-th order harmonics. Specifically,
 5 it is better that $\theta_1 = 9^\circ$, $\theta_2 = 18^\circ$. Of course, formulae of lower two rows are used for reducing the 7-th order harmonics.

The principle for reducing sound of the motor having the above arrangement is similar to that of the first embodiment. Thus the description is omitted.

10 Fig. 15 is a schematic diagram illustrating a modified example of this embodiment.

This modified example employs planar permanent magnets instead the curved permanent magnets.

Therefore, sound can be reduced when this modified example is employed.

15 (Third Embodiment)

Fig. 16 is a schematic diagram illustrating an arrangement of a rotor of a motor of third embodiment according to the present invention.

In the rotor 31, multiple permanent magnets 33 (in this embodiment, the rotor is of 4 poles, so 4 permanent magnets) are embedded in the interior of
 20 the rotor core 32.

A non-magnetic layer 34 (hereinafter, referred to as "first non-magnetic layer") elongates in vicinity of between poles to the vicinity of the rotor surface, the non-magnetic layer 34 being continuous to the peripheral direction edge section of each permanent magnet 33. Further, a
 25 second non-magnetic layer 35 is provided in pole center side of the first

non-magnetic layer 34 and in vicinity of the rotor surface. Wherein, the non-magnetic layer is a through hole or an air layer.

An angle between the pole center side edge section of adjacent section to the rotor surface of the first non-magnetic layer 34 and the between poles is expressed with $\theta 5$, while an angle between the pole center side edge section of adjacent section to the rotor surface of the second non-magnetic layer 35 and the between poles is expressed with $\theta 6$.

The first non-magnetic layer 34 and second non-magnetic layer 35 are independent from one another. An auxiliary reinforcement rib 32a made of rotor core is interposed between them.

Further, the width of the rotor core section (hereinafter, referred to as "first bridge 32b1", and "second bridge 32b2") has points of inflection 36a and 36b, the rotor core section being sandwiched by the first non-magnetic layer 34, second non-magnetic layer 35 and the rotor surface. Angles between respective point of inflection 36a and 36b and between poles are expressed with $\theta 7$ and $\theta 8$. The angles $\theta 5$, $\theta 6$, $\theta 7$ and $\theta 8$ are determined to be $0 < \theta 5 < 180/(5 \cdot P_n)$

and

$$180/(5 \cdot P_n) \leq \theta 6 \leq 180 \times 2/(5 \cdot P_n)$$

and

$$0 < \theta 7 < 180/(7 \cdot P_n)$$

and

$$180/(7 \cdot P_n) \leq \theta 8 \leq 180 \times 2/(7 \cdot P_n)$$

and

$$\theta 7 < \theta 5 < \theta 8 < \theta 6.$$

In this embodiment, the pole pair number P_n is 2, so that the angles are determined to be $\theta_6=18^\circ$, $\theta_8=12.9^\circ$, $\theta_5=9^\circ$, $\theta_7=6.4^\circ$.

Wherein, the points of inflection 36a and 36b are crossing points of extents where the widths of the first bridge 32b1 and second bridge 32b2 are constant and extents where the widths of the first bridge 32b1 and second bridge 32b2 are gradually increasing. The change in magnetic flux density distribution on the rotor surface becomes steep at these points.

The magnetic flux density distribution on the rotor surface of this embodiment is illustrated in Fig. 17.

As is apparent from Fig. 17 and the description of the first embodiment, 7-th order harmonics is canceled by the points of inflection 36a and 36b, while 5-th order harmonics is canceled by pole center side edge section of the section adjacent to the rotor surface and by pole center side edge section of the section adjacent to the rotor surface of the second non-magnetic layer 35.

Fig. 18 illustrates a comparison in induction voltage waveforms, one for a case where the second non-magnetic layer 35 does not exist, the other for this embodiment. Table 1 illustrates a comparison in amplitude of higher harmonics components. Further, higher harmonics component of noise when the motor is driven as a motor for compressor is illustrated in Fig. 19.

Table 1

| Induction voltage | percentage with respect to fundamental wave | |
|-------------------|---|------|
| | Without | With |

| | non-magnetic layer | non-magnetic layer |
|----------------------|--------------------|--------------------|
| 5-th order harmonics | 8.24 | 0.01 |
| 7-th order harmonics | 2.68 | 0.03 |

Further, the shapes of the non-magnetic layer 34 and 35 are not limited to the shapes of this embodiment. It may be good that, for example, as is illustrated in Fig. 20, the widths of the bridges 37b1 and 37b2 are separated into small width sections 37b11, 37b21 and large width sections 37b12, 37b22, and that varying points of the small width sections 37b11, 37b21 and the large width sections 37b12, 37b22 are considered to be points of inflection 38a, 38b.

(Fourth Embodiment)

Fig. 21 is a schematic diagram illustrating an arrangement of a rotor of a motor of fourth embodiment according to the present invention.

In the rotor 41, permanent magnets are embedded in the interior of the rotor core 42. The permanent magnets are divided into two layers in radial direction for every pole (43: permanent magnet at inner side of the rotor, and 44: permanent magnet at outer side of the rotor). Further, the peripheral direction edge section 43a, 44a of each permanent magnet 43, 44 elongates in the vicinity between poles to the vicinity of the rotor surface.

The peripheral direction edge sections 43a, 44a of the permanent magnet 43 at the inner side of the rotor and the permanent magnet 44 at the outer side of the rotor are independent from one another. A so-called q-axis magnetic flux path 42a made of rotor core is interposed between them.

Due to the existence of the q-axis magnetic flux path 42a, the q-axis

inductance L_q can be made greater. Therefore, reluctance torque of greater part can be used, and the magnetic flux of the permanent magnet can be increased without increase of the rotor in size.

Further, the peripheral direction edge section 43a of the permanent magnet 43 at the inner side of the rotor elongates in the vicinity between poles to the vicinity of the rotor surface, and the peripheral direction edge section 44a of the permanent magnet 44 at the outer side of the rotor also elongates in the vicinity between poles to the vicinity of the rotor surface. Wherein, air layers and the like may exist at the peripheral direction edge sections 43a, 44a of the permanent magnets 43, 44. An angle between the pole center side edge section of the peripheral direction edge section 43a of the permanent magnet 43 at the inner side of the rotor and between poles is expressed with θ_9 , and an angle between the pole center side edge section of the peripheral direction edge section 44a of the permanent magnet 44 at the outer side of the rotor and between poles is expressed with θ_{10} .

Further, the width of the rotor core section (hereinafter, referred to as "first bridge 42b1", and "second bridge 42b2") has points of inflection 46a and 46b, the rotor core section being sandwiched by the peripheral direction edge section 43a of the permanent magnet 43 at the inner side of the rotor, the peripheral direction edge section 44a of the permanent magnet 44 at the outer side of the rotor and the rotor surface. Angles between respective point of inflection 46a, 46b and between poles are expressed with θ_{11} and θ_{12} . The angles θ_9 , θ_{10} , θ_{11} and θ_{12} are determined to be $0 < \theta_9 < 180/(5 \cdot P_n)$

and

$$180/(5 \cdot P_n) \leq \theta_{10} \leq 180 \times 2/(5 \cdot P_n)$$

and

$$0 < \theta_{11} < 180/(7 \cdot P_n)$$

and

$$5 \quad 180/(7 \cdot P_n) \leq \theta_{12} \leq 180 \times 2/(7 \cdot P_n)$$

and

$$\theta_{11} < \theta_9 < \theta_{12} < \theta_{10}.$$

In this embodiment, the pole pair number P_n is 2, so that the angles are determined to be $\theta_{10}=18^\circ$, $\theta_{12}=12.9^\circ$, $\theta_9=9^\circ$, $\theta_{11}=6.4^\circ$.

10 The sound reduction operation and effect in this embodiment is similar to those of the third embodiment, therefore description is omitted.

The invention of first aspect has characteristic effect such that odd number order harmonics, the odd number being equal to or greater than 3, of the magnetic flux distribution waveform (induction voltage waveform) can be
15 reduced and unnecessary radial force and thrust force can be prevented from occurrence, while sufficient magnetic flux can be maintained.

The invention of second aspect has characteristic effect such that odd number order harmonics, the odd number being equal to or greater than 3 other than multiples of 3, can be reduced, and that effect similar to those of
20 first aspect can be realized.

The invention of third aspect has characteristic effect such that odd number order harmonics, the odd number being equal to or greater than 13 other than multiples of 3, can be reduced, and that effect similar to those of first aspect can be realized.

25 The invention of fourth aspect has characteristic effect such that 5-th

order harmonics or 7-th order harmonics can be reduced, and that effect similar to those of second aspect can be realized.

The invention of fifth aspect has characteristic effect such that mechanical strength can be improved, and that effect similar to those of
5 fourth aspect can be realized.

The invention of sixth aspect has characteristic effect such that effects similar to those of fourth aspect or fifth aspect can be realized by taking symmetry into consideration.

The invention of seventh aspect has characteristic effect such that
10 silencing can be realized, and that effects similar to those of fourth aspect or fifth aspect can be realized.

The invention of eighth aspect has characteristic effect such that effects similar to those of fourth aspect or fifth aspect can be realized by taking symmetry into consideration.

15 The invention of ninth aspect has characteristic effect such that silencing can be realized, and that effects similar to those of fourth aspect or fifth aspect can be realized.

The invention of tenth aspect has characteristic effect such that effects similar to those of one of first aspect to fourth aspect can be realized
20 even when the permanent magnet is divided into multiple parts, some parts corresponding to inner side of the rotor and other parts corresponding to outer side of the rotor.

The invention of eleventh aspect has characteristic effect such that effects similar to those of tenth aspect can be realized by taking symmetry
25 into consideration.

The invention of twelfth aspect has characteristic effect such that silencing can be realized, and that effects similar to those of tenth aspect can be realized.

5 The invention of thirteenth aspect has characteristic effect such that effects similar to those of tenth aspect can be realized by taking symmetry into consideration.

The invention of fourteenth aspect has characteristic effect such that silencing can be realized, and that effects similar to those of tenth aspect can be realized.